

CAM SHAFT MATERIAL SELECTION USING MULTI-OBJECTIVE OPTIMIZATION ON THE BASIS OF RATIO ANALYSIS - (MOORA) METHOD

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ABSTRACT

Material selection is one of the first and foremost steps taken during the design of any product. With the advent of a wide choice of materials, the design engineer is spoilt for choices, as he has got a wide array of choices. However, the selection of the right material is as vital as the manufacturing process itself. The selection of the right work piece material is vital, as it results in better product, while taking care of the cost optimisation. In the current research work, the multi-objective optimization on the basis of ratio analysis (MOORA) is used. MOORA is used to solve multi-criteria (objective) optimization problem in material selection for cam shaft production. To begin with, a comprehensive list of materials is obtained from all prospective materials while taking into account multi-conflicting material selection attributes. The various influencing factors such as hardness, thermal conductivity, ultimate tensile strength etc. are taken into account. The assessment value of the alternatives with respect to all the criteria is calculated and compared for all the six materials chosen. The final ranking is done, based on the basis of the assessment values of the six alternatives. The final results indicate that the carburised steel is the best suited alternative for cam shaft material, while nitride steel comes a close second.

KEYWORDS: Cam Shaft Material Selection, MOORA Method, Multi-Criteria Optimisation Problem & Multi-Conflicting Material Selection Attributes

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INTRODUCTION

The selection of right work piece material is a key to success in today's day by day growing competitive environment [1-3]. While selecting material for a particular purpose, the properties of the material need to be studied carefully. The current research work deals with the selection of the most suitable material for cam shaft in an automobile industry. The selection of the proper material for a particular purpose is often very cumbersome, due to a number of reasons. In such material selection problems, there are trade-offs amongst a number of decisive factors such as manufacturing cost, availability, market values and desired properties. The process is not only time consuming due to the availability of a wide array of choices, but also often there are conflicts in the objectives and criteria, and it involves trade-offs. Hence, the problem in question belongs to multi criteria decision making (MCDM). Here, there is a need to eliminate the unsuitable choices and to select the most suited alternative using a logical approach [4].

LITERATURE REVIEW

The researchers in the past have presented a number of mathematical approaches for solving the material selection problem for an engineering application. FikriDweiri & Faris M. Al-Oqla used AHP for material selection [5], while R Kumar et al. used TOPSIS approach for material selection for engineering design optimization [6]. Prasenjit Chatterjee & Shankar Chakraborty used COPRAS method for material selection for cost effective manufacturing [7]. Although the researchers have applied various mathematical approaches till date for solving several material selection problems, it is observed that all these methods the rankings of the alternative materials are affected by the criteria weights and normalization procedure adopted to make the elements of the decision matrix dimensionless and comparable. Hence the need arises for a simpler and systematic approach in order to solve the material selection problems. In this paper, the applications of multi-objective optimization on the basis of ratio analysis (MOORA) are illustrated to rank the alternatives more precisely and without being influenced by the criteria weights and normalization procedure.

Multi-Objective Optimization on the Basis of Ratio Analysis Method

The current research work deals with the use of 'MOORA' method to select the best suited material while considering a number of criteria such as, surface fatigue limit, bending fatigue limit, core hardness, surface hardness and ultimate tensile strength. Multi objective optimization basically deals with the simultaneous optimizing two or more criteria which are subject to certain constraints. Typical examples of a multi objective optimization problem can be minimizing weight while maximizing the strength or, minimizing the fuel consumption of a vehicle while maximizing its performance. It is here that 'MOORA' method comes into play. While selecting an alternative, one has to come across a number of conflicting criteria, some of whom may be beneficial while the other may not be so. 'MOORA' method takes into account both the beneficial as well as non-beneficial criteria and ranks the various alternatives from an array of choices. To begin with, a decision matrix is formed which shows the performance of various alternatives w.r.t the various criteria. A typical decision matrix is shown below.

$$X = \begin{bmatrix} X_{11} & X_{12} & X_{13} & X_{14} & \dots & X_{1n} \\ X_{21} & X_{22} & X_{23} & X_{24} & \dots & X_{2n} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ X_{m1} & X_{m2} & X_{m3} & X_{m4} & \dots & X_{mn} \end{bmatrix}$$

Where X_{ij} is the performance measure of i^{th} alternatives on j^{th} criterion, m is the number of alternatives and n is the number of criteria. The decision matrix is then normalised in order that, it becomes dimensionless and all its members are comparable. This normalisation procedure is a ratio system, in which, the performance of an alternative on a criterion is compared to a denominator, which is a representative for all the alternatives concerning that criterion. Here X_{ij} , which is the performance measure is dimensionless number in the $[0,1]$ interval representing the normalized performance of the i^{th} alternative on j^{th} criterion. It is worth mentioning here that the elements of the decision matrix are normalized without considering the type of the criterion (i.e., beneficial or non-beneficial). Hence, it becomes imperative to use the equation no. 1, so that the maximum criteria value becomes less than one.

$$X_{ij} = \frac{X_{ij}}{\sum_{i=1}^m X_{ij}} \quad (1)$$

While using the MOORA method, the normalized values are added for the beneficial factors while they are subtracted for the non-beneficial factors, as given in the following expression as give in equation 2:

$$Y_i = \sum_{j=1}^g X_{ij} - \sum_{j=g+1}^n X_{ij} \quad (2)$$

Where g is the number of criteria to be maximized, $(n-g)$ is the number of criteria to be minimized and Y_i is the assessment value of i^{th} alternative with respect to all the criteria. When sorted in descending order, the best alternative is that which has the highest assessment value. Finally an ordinal ranking of Y_i values is done in order to derive the final preference of the candidate alternatives.

Validation of the Proposed Methodology

Step 1: Decide the decision matrix, which is shown in Table 3 as obtained from equation (1),

Step 2: The decision matrix is normalized by using the equation (2),

Step3: Calculate Y_i , the assessment value of i^{th} alternative with respect to all the criteria by subtracting the non-beneficial criteria from the beneficial criteria, as per the equation three. In the current research work, seven selection parameters are selected as shown in table 1 below.

Table 1: Material Selection Criteria

Criteria	Unit
Density	(kg/m ³)
Thermal conductivity	(W/m-K)
Ultimate Tensile Strength	(MPa)
Yield Strength	(MPa)
Fatigue Strength	(MPa)
Hardness	(BHN)
%age Elongation	—

The alternative material list is shown in table 2, where, the proper material is to be selected from six alternatives for the manufacturing of cam shafts in an automobile industry.

Table 2: List of Alternative Materials

Sl. No.	Material
1	Cast iron
2	ZC63 Alloy
3	Nitrided Steel
4	AZ91 Alloy
5	ZE63 Alloy
6	Carburized Steel

The Table 3 shows the decision matrix of selection of material on the basis of required criteria for cam shaft manufacturing.

Table 3: Decision Matrix for Materials

	Density (kg/m ³)	Thermal Conductivity (W/m-K)	UTS (Mpa)	YTS (Mpa)	Fatigue Strength (Mpa)	Hardness (BHN)	%Age Elongation
Cast iron	7300	48	245	160	100	210	3.06
ZC63 Alloy	1870	122	240	125	93	60	4.5
Nitrided Steel	8220	42	1250	590	470	750	13
AZ91 Alloy	1810	72.7	230	150	97	63	3
ZE63 Alloy	1870	109	295	190	79	75	7
Carburized Steel	7850	46.6	780	833	458	341	2.90

DICUSSIONS AND CONCLUSIONS

In the current research work, Multi-objective optimization on the basis of ratio analysis method (MOORA) is used to select the best material for cam shaft manufacturing from a wide range of choices available. As MOORA method performs non-subjective analysis of the alternatives, it does not require weights of the criteria, because it incorporates in-house normalization and treats all the criteria as equally important. The normalized decision matrix is shown in table 4 below and assessment value of each alternative i.e., Y_i , with respect to criteria is calculated by using equation (2).

Table 4: Normalised Decision Matrix

	Density (kg/m ³)	Thermal conductivity (W/m-K)	UTS (Mpa)	YTS (Mpa)	Fatigue Strength (Mpa)	Hardness (BHN)	%age Elongation
Cast iron	0.25242	0.109017	0.080592	0.078125	0.077101	0.140093	0.091452
ZC63 Alloy	0.064661	0.277084	0.078947	0.061035	0.071704	0.040027	0.134489
Nitrided Steel	0.284232	0.09539	0.411184	0.288086	0.362375	0.500334	0.388524
AZ91 Alloy	0.062586	0.165115	0.075658	0.073242	0.074788	0.042028	0.089659
ZE63 Alloy	0.064661	0.247558	0.097039	0.092773	0.06091	0.050033	0.209205
Carburized Steel	0.271438	0.105837	0.256579	0.406738	0.353123	0.227485	0.086671

Finally, the assessment value of each alternative with respect to criteria is calculated using equation 2, and the final ranking of the alternative materials is done. This ranking and the assessment values are shown in table 5 below.

Table 5: Performance Score and Rank Comparison of the Alternatives

Material	Y_i	Rank
Cast iron	0.141056	6
ZC63 Alloy	0.329647	3
Nitrided Steel	0.984613	2
AZ91 Alloy	0.278586	4
ZE63 Alloy	0.274447	5
Carburized Steel	0.991653	1

The final ranking of materials is done on their respective assessment value (Y_i), and is indicated in the table 5 above. By using the MOORA method, it is clearly indicated that Carburised steel is the best alternative for cam shaft manufacturing and Nitrided steel comes a close second. Also, it becomes clear that Cast iron is the most unsuitable

material for the purpose.

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